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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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<p>(21) International Application Number: PCT/US88/03184</p> <p>(22) International Filing Date: 14 September 1988 (14.09.88)</p> <p>(31) Priority Application Number: 097,592</p> <p>(32) Priority Date: 15 September 1987 (15.09.87)</p> <p>(33) Priority Country: US</p> <p>(71) Applicant: PLASMA SCIENCE, INC. [US/US]; 272 Harbor Boulevard, Belmont, CA 94002 (US).</p> <p>(72) Inventors: ROSE, Peter, W. ; 1000 Almanor Avenue, Menlo Park, CA 94025 (US). ROUGH, J., Kirkwood, H. ; 262 South 14th Street, San Jose, CA 95112 (US).</p> <p>(74) Agent: GUILLOT, Robert, O.; Suite 201, 3211 Scott Blvd., Santa Clara, CA 95051 (US).</p>		<p>(81) Designated States: AT (European patent), BE (European patent), CH (European patent), DE (European patent), FR (European patent), GB (European patent), IT (European patent), JP, KR, LU (European patent), NL (European patent), SE (European patent).</p> <p>Published With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</p>
<p>(54) Title: MULTIPLE ELECTRODE PLASMA REACTOR POWER DISTRIBUTION SYSTEM</p> <div data-bbox="324 1155 1266 1596"> </div> <p>(57) Abstract</p> <p>A multiple electrode plasma reactor arranged with electrical circuitry which allows for improved power distribution and plasma uniformity without requiring perfectly symmetrical power feeds, the high frequency RF power from generator (102) is introduced into a matching network (104) in the normal fashion, however, upon exiting match network (104) the power is fed through a differential drive transformer (106). The power from the output coil (107) of the transformer is then split, and fed through separated feed through circuits (108) and (110) respectively to each of the powered electrodes (112) and (114) respectively disposed within the grounded chamber (118). To achieve uniformity, the electrodes are preferably formed as planar members and the spacing between the powered electrodes (112) and (114) and the grounded surfaces (116), (120) and (122) is equal throughout. The differential drive transformer circuit applies the same RF current to each powered electrode creating a uniform plasma between the two powered electrodes and the grounded surfaces.</p>		

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SPECIFICATION

"Multiple Electrode Plasma Reactor
Power Distribution System"

BACKGROUND OF THE INVENTION

Field of the Invention

This present invention relates generally to electrical circuitry for gas plasma systems for the surface modification of a workpiece and more particularly to circuitry for multiple electrode gas plasma reactors.

Description of Prior Art

Gas plasma modification of surfaces has been found to be quite useful for a multitude of applications crossing many fields. These surface modifications include, but are not limited to, etching (metals, dielectrics, polymers, etc.), deposition (metals, dielectrics, polymers, etc.), etchback and desmear of printed circuit boards, and chemical surface treatment (including cleaning). A common problem which is encountered in plasma processing is the difficulty of obtaining uniform process results across the reactor. This problem is particularly evident in reactors which have multiple process areas utilizing a plurality of electrodes as was demonstrated by James W. Wilson, Plasma Etching of Organic Materials in Large Multicell Reactors, Electrochemical Society Extended Abstracts, 84-2, Abstract No. 369, Page 521, 1984 in a reactor used to desmear and etchback printed circuit boards.

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1 One cause of this phenomena is the difference in impedance in each
2 of the electrical feeds to the driven electrodes brought about by having
3 electrode feeds which are not identical or symmetrical to each other. This
4 results in a non-symmetrical distribution of power among the electrodes
5 which manifests itself in a non-uniform plasma and thus non-uniform
6 processing.

7
8 U.S. Patent No. 4,381,965 illustrates a plasma etching reactor
9 which has multiple pairs of electrodes which do not have symmetrical
10 feeds. Each driven electrode receives the RF excitation by way of separate
11 variable capacitances each in series with the input to the electrode plates.
12 Uniform etching performance in each plasma region is achieved
13 empirically by tuning each of the latter capacitances, determining the
14 degree of etching occurring in each plasma region, re-adjusting the
15 capacitances, observing the changes and continuing the testing and re-
16 adjusting procedures until the etching effects are balanced. This process
17 is lengthy and can be quite arduous. In addition, these settings are only
18 true for a very narrow range of process parameters (power, pressure, gas
19 utilized, load, etc.) and must be repeated when the parameters are changed
20 significantly.

21
22 Another cause of non-uniform plasmas is the change in the
23 electrical characteristics of the plasma due to loading effects, i.e.,
24 placement of multiple parts within a reactor. In U.S. Patent No. 4,282,077,
25 which describes a plasma reactor (a multiple electrode system) used for
26 desmear and etch-back of printed circuit boards, this problem was

1 overcome by utilizing variable inductances in series with each of the
2 electrodes. Again uniformity is only obtained empirically using a lengthy
3 and arduous procedure of tuning individual inductors that is similar to the
4 one mentioned above in U.S. Patent 4,381,965. In addition, the variable
5 inductors are positioned within the reactor and thus exposed to the plasma
6 conditions where they are subject to the atmospheric permeability
7 variation as the plasma's electrical characteristics are changed. This
8 feature makes a wide pressure use at a single setting difficult if not
9 impossible to achieve. The gas chemistry and the process conditions
10 which affect the electrical characteristics of the plasma also contribute
11 to this variability.

12
13 Another example of a multiple electrode system is demonstrated
14 by U.S. Patent No. 4,474,659 where the workpieces themselves are acting
15 as electrodes and multiple generators are used to obtain good uniformity.
16 In this case, however, the goal is not to achieve electrical equality among
17 the electrodes, but to vary the RF excitation power to each individual
18 electrode to compensate for differences in gas composition and flow
19 between various electrodes. In this patent is also disclosed a planar type
20 electrode arrangement which is composed of multiple areas driven by
21 different generators or by a single generator with attenuation of the
22 individual feeds to the different areas of the electrode.

23 24 SUMMARY OF THE INVENTION

25 It is an object of the present invention to provide a new and
26 improved apparatus for plasma processing for the surface modification of

1 workpieces whether it be by etching, deposition or some other means of
2 surface treatment, in an ionized gas plasma in a multiple-electrode
3 environment.

4

5 It is another object of the present invention to provide a multiple
6 electrode plasma reactor which permits the uniform processing of
7 workpieces independent of the loading.

8

9 It is a further object of the present invention to provide a multiple
10 electrode plasma reactor circuit which distributes the power evenly to
11 each of the electrodes providing uniform plasma processing
12 characteristics across the reactor.

13

14 It is yet another object of the present invention to provide a
15 multiple electrode plasma reactor circuit which eliminates the necessity
16 for tuning individual circuit elements in order to obtain uniform process
17 results.

18

19 It is yet a further object of the present invention to provide a
20 multiple electrode plasma reactor circuit which eliminates the need for
21 multiple generators and/or multiple matching networks.

22

23 It is still another object of the present invention to provide a
24 multiple electrode plasma reactor circuit which eliminates tuning devices
25 and replaces them with a single component which does not require tuning.

26

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1 It is still a further object of the present invention to provide a
2 multiple electrode plasma reactor circuit which provides power to
3 electrodes located in two different chambers and creates uniform plasmas
4 within said chambers and which does not require tuning of the individual
5 chambers relative to each other.

6
7 The present invention comprises electrical circuitry which
8 creates uniform plasma characteristics in multiple electrode plasma
9 reactors. It utilizes an electrical power-splitting element in the circuitry
10 which provides power to the powered electrodes and minimizes the effect
11 of the differing impedances of the power circuits and chamber
12 characteristics. Such power-splitting elements as a differential drive
13 transformer and/or a center-tapped coil are utilized, and the requirement
14 in the prior art for tuning the power circuit elements is obviated.

15
16 It is an advantage of the present invention that it provides a new
17 and improved apparatus for plasma processing for the surface
18 modification of workpieces whether it be by etching, deposition or some
19 other means of surface treatment, in an ionized gas plasma in a multiple-
20 electrode environment.

21
22 It is another advantage of the present invention that it provides a
23 multiple electrode plasma reactor which permits the uniform processing
24 of workpieces independent of the loading.

25

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1 It is a further advantage of the present invention that it provides a
2 multiple electrode plasma reactor circuit which distributes the power
3 evenly to each of the electrodes providing uniform plasma processing
4 characteristics across the reactor.

5
6 It is yet another advantage of the present invention that it
7 provides a multiple electrode plasma reactor circuit which eliminates the
8 necessity for tuning individual circuit elements in order to obtain uniform
9 process results.

10
11 It is yet a further advantage of the present invention that it
12 provides a multiple electrode plasma reactor circuit which eliminates
13 multiple generators and/or multiple matching networks.

14
15 It is still another advantage of the present invention that it
16 provides a multiple electrode plasma reactor circuit which eliminates
17 tuning devices and replaces them with a single component which does not
18 require tuning.

19
20 It is still a further advantage of the present invention that it
21 provides a multiple electrode plasma reactor circuit which provides power
22 to electrodes located in two different chambers and creates uniform
23 plasmas within said chambers and which does not require tuning of the
24 individual chambers relative to each other. _____ These and other
25 objects and advantages of the present invention will become apparent to

1 one skilled in the art from consideration of the drawings and ensuing
2 description of the preferred embodiments.

3
4 IN THE DRAWING

5 Fig. 1 is an electrical circuit diagram depicting a prior art L type
6 reactive matching network for a single electrode chamber;

7
8 Fig. 2 is a circuit diagram for a prior art multiple electrode
9 reactor;

10
11 Fig. 3 is an electrical schematic of a first preferred embodiment
12 of the present invention;

13
14 Fig. 4 is an electrical schematic diagram of another preferred
15 embodiment of the present invention;

16
17 Fig. 5 is an electrical schematic of a further preferred
18 embodiment of the present invention depicted in Fig. 4;

19
20 Fig. 6 is an electrical schematic of the present invention as
21 applied to two single electrode chambers.

22
23 DESCRIPTION OF THE PREFERRED EMBODIMENT

24 Plasma chambers driven at frequencies of less than 100 MHz
25 usually contain an electrode driven by the power generator and a grounded
26 return path. Between the powered electrode and the ground electrode is a

1 space in which the AC discharge takes place. The problem to be addressed
2 is the optimal delivery of high frequency energy from a generator of fixed
3 output impedance to a load which typically has other than optimal
4 impedance. In prior art single electrode plasma chambers this is
5 accomplished through the use of the usual L type reactive matching
6 network, usually transforming the resistive nature of a plasma in series
7 with the sheath capacitance near the electrode, to a 50 ohm source. A
8 typical circuit diagram representation of the L type reactive matching
9 network is presented in Fig. 1.

10
11 As depicted in Fig. 1, an L type reactive matching network 10 for a
12 single electrode chamber includes an RF generator 12 shown with a source
13 impedance 14, which is typically 50 ohms, an L type matching network 16,
14 and a single powered electrode 18 together with a single grounded
15 electrode 20 within a chamber 22. The matching network 16 includes a
16 capacitance 24 and an inductance 26. When activated, the single powered
17 electrode chamber 22 may be electrically represented as a capacitance 28,
18 shown in phantom, and resistance 30, shown in phantom, which represent a
19 simple model of the capacitance of the plasma sheath Faraday space and
20 the resistance of the plasma. The operation and dynamics of this circuit
21 representation are known in the prior art and well understood by the
22 ordinarily skilled worker.

23
24 In a multiple electrode reactor arrangement symmetry is critical
25 for achieving a uniform voltage profile along and between each electrode.
26 Without good voltage distribution plasma uniformity becomes very poor

1 often to the extent that different zones in the reactor will yield very
2 different reactivities and the uniformity of plasma treatment will become
3 unacceptable. As indicated hereinabove in U.S. Patents 4,282,077 and
4 4,381,965, a problem with multiple electrode chambers has been that
5 individual tuning of each of several inductors, or their equivalent
6 capacitors, is required. The multiple electrode reactor thus proves to have
7 special problems involving the impedance matching of multiple electrodes,
8 having variable surface areas due to loading, and non-symmetrical RF feed
9 lengths.

10
11 A representative diagram of a typical prior art three-electrode
12 reactor is presented in Fig. 2. As depicted therein the three-electrode
13 reactor circuit diagram 50 includes a first powered electrode 52, a second
14 powered electrode 54 and a grounded electrode 56 disposed between the
15 powered electrodes 56 and 54 and within a grounded chamber 58. Two
16 plasmas are created in the spaces between the grounded electrode 56 and
17 the two powered electrodes 52 and 54. The grounded walls of the chamber
18 58, principally the upper wall 60 and lower wall 62 typically act as
19 grounded electrodes relative to the powered electrodes 52 and 54
20 respectively, such that plasmas are also created between the powered
21 electrodes 52 and 54 and the grounded walls 60 and 62 respectively. A
22 generator 66 and a matching network 68 supply power to the two powered
23 electrodes 52 and 54.

24
25 When materials to be treated in the plasma chamber are unevenly
26 loaded onto the reactor shelves, the surface area and thus the capacitive

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1 coupling differs between the shelves of the chamber. This effect
2 combined with the differences in feed line inductance produces two
3 distinctly different load impedances between the multiple electrodes
4 within the chamber. Two variable inductors, 70 and 72 enable the user to
5 individually tune the two power circuits to the powered electrodes 52 and
6 54 respectively, such that the plasma fields generated between the two
7 powered electrodes and the grounded surfaces will be uniform. Such
8 uniformity is desired to obtain similar results on work pieces placed on
9 different shelves within the chamber. The device depicted in Fig. 2 and
10 described hereinabove is similar in operation to that described in U.S.
11 Patent 4,282,077. Of course, as described in U.S. Patent 4,381,965, the
12 two variable inductors 70 and 72 can be replaced by two variable
13 capacitors (not shown) which also permit the individual tuning of the two
14 powered circuits to obtain uniform results.

15
16 In a multiple electrode reactor arrangement symmetry is critical
17 for achieving a uniform voltage profile along and between each electrode.
18 Without good voltage distribution plasma uniformity becomes very poor
19 often to the extent that different zones in the reactor will yield very
20 different reactivities and the uniformity of plasma treatment will become
21 unacceptable. As indicated hereinabove in U.S. Patents 4,282,077 and
22 4,381,965, a problem with multiple electrode chambers has been that
23 individual tuning of each of several inductors, or their equivalent
24 capacitors, is required.

1 The present invention is a multiple electrode plasma reactor
2 having a configuration and electrical circuitry which allows for improved
3 power distribution and plasma uniformity without requiring perfectly
4 symmetrical power feeds. In a preferred embodiment 100 of the present
5 invention, as depicted in Fig. 3, the high frequency RF power from
6 generator 102 is introduced into a matching network 104 in the normal
7 fashion, however, upon exiting match network 104 the power is fed
8 through a differential drive transformer 106. The power from the output
9 coil 107 of the transformer is then split, whereby each end 109 and 111 of
10 the output coil 107 of the transformer 106 is fed through separate
11 feedthrough circuits 108 and 110 respectively to each of the powered
12 electrodes 112 and 114 respectively disposed within the grounded
13 chamber 118. The central electrode 116 in the chamber 118 is grounded,
14 and the upper wall 120 and lower wall 122 of the grounded chamber 118
15 also act as grounded electrodes. To achieve uniformity, the electrodes are
16 preferably formed as planar members and the spacing between the powered
17 electrodes 112 and 114 and the grounded surfaces 116, 120 and 122 is
18 equal throughout. Each RF power feedthrough circuit 108 and 110 may be
19 provided with a DC blocking capacitor 124 and 126 respectively. The
20 output coil 107 may have a grounded center tap 128, and alternatively, a
21 single DC blocking capacitor (not shown) may be located in the grounded
22 center tap. The blocking capacitors 124 and 126 are utilized to prevent
23 self-bias drain of the powered electrodes. The effect of the differential
24 drive transformer power circuit is to present to the matching network 104
25 one load impedance to be corrected. The differential drive transformer
26 circuit applies virtually the same RF current to each powered electrode

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1 112 and 114, balancing the discharge power evenly and creating uniform
2 plasmas between the two powered electrodes 112 and 114 and the
3 grounded surfaces 116, 120 and 122. The circuit configuration 100
4 therefore compensates for the variations caused by differing electrical
5 feedthrough designs, shelf loading effects and other variables, and thus
6 facilitates uniform plasmas in the processing areas of the reactor
7 chamber.
8

9 A second preferred embodiment 200 is depicted in Fig. 4. This
10 embodiment includes the use of a single center-tapped coil 202 which
11 replaces the differential drive transformer 106 and blocking capacitors
12 124 and 126, shown in Fig. 3. Thus, the electrical power is fed from the
13 match network 206 through the center tap 203 of coil 202 and split,
14 whereby power is fed through each end 205 and 207 of coil 202 and then
15 through separate feedthrough circuits 208 and 210 respectively to each of
16 the powered electrodes 212 and 214 respectively disposed within the
17 grounded chamber 218. The central electrode 216 is grounded and the
18 upper wall 220 and lower wall 222 of the grounded chamber 218 also
19 function as grounded surfaces. The generator 204, match network 206 and
20 chamber electrode configuration are similar to those depicted in Fig. 3. A
21 DC blocking capacitor 224 may be located in the RF power line between the
22 matching network 206 and the center-tapped coil 202.
23

24 The contribution of the center-tapped coil 202 to the power
25 circuit is to tightly couple the powered electrodes 212 and 214 together
26 The center-tapped coil 202 thus in effect places the multiple electrodes

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1 in series in a tightly coupled fashion such that the matched network sees
2 one load impedance presented to it. Any impedance imbalance between the
3 two powered electrode circuits 208 and 210 will cause a differential
4 current to flow through the coupled inductor 202. The net result is that
5 the electrode power distribution system is self-balancing, even though
6 different shelf loading configurations and other process parameters are
7 utilized. Thus a uniform plasma is established in multiple plasma zones
8 concurrently, and the uniform processing of workpieces, independent of
9 the loading, is thus achieved.

10
11 Fig. 5 depicts an extension of the preferred embodiments depicted
12 in Figs. 3 and 4 as applied to a plurality of electrodes in a plurality of
13 chambers and/or zones within a chamber. The multiple electrode circuit
14 300 includes a plurality of reactive circuit elements, shown as center-
15 tapped coils, which are configured to receive power from an RF generator
16 301 through a single matching network 303. The center-tapped coils could
17 be replaced by differential drive transformers as is seen by comparing
18 Figs. 3 and 4 hereinabove. As depicted in Fig. 5, a center-tapped coil 302
19 delivers RF power to the center tap of two subsequent center-tapped coils
20 304 and 306 which feed power to two different chambers 318 and 328.
21 Coil 306 thereafter delivers power to the center tap of two further
22 center-tapped coils 308 and 310. Coil 304 delivers power to two powered
23 electrodes 312 and 314 which create plasmas in association with
24 grounded electrode 316 and the chamber walls within one chamber 318.
25 In relation to the other chamber 328, coil 308 delivers power to powered
26 electrodes 322 and 324 which create plasma fields in association with

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1 grounded electrodes 326 and 330 and the chamber wall of chamber 328,
2 and coil 310 delivers power to two powered electrodes 332 and 334 which
3 create plasma fields in relation to grounded electrodes 330 and 336 and
4 the chamber wall of chamber 328. Plasma fields generated in association
5 with coil 304 will be uniform. Likewise, assuming that shelf spacing and
6 other parameters are equal, the plasma fields generated in relation to
7 powered electrodes 322, 324, 332 and 334 from coils 308 and 310 within
8 chamber 328 will all be uniform. However, owing to the further splitting
9 of the power from coil 306 into coils 308 and 310, the plasma fields
10 generated in association with coil 304 will have twice the power as the
11 plasma fields associated with coils 308 and 310. Thus, the splitter coil
12 concept may be utilized to create chambers having a plurality of powered
13 electrodes interspersed with ground electrodes, wherein uniform plasmas
14 will be created between the various powered and grounded surfaces.

15
16 Fig. 6 is an electrical schematic of the present invention as
17 applied to two single electrode chambers. As depicted in Fig. 6, the two-
18 chamber circuit 400 includes a center-tapped coil 402 which receives RF
19 power from an RF generator 404 through a matching network 406. A DC
20 blocking capacitor 408 may be employed in the RF power line between the
21 matching network 406 and the center tap of the coil 402. RF power from
22 one output end 410 of coil 402 is provided to a powered electrode 412
23 disposed within a first reactor chamber 414. Output power from the other
24 end 416 of coil 402 is supplied to a second powered electrode 418 which
25 is disposed within a second reactor chamber 420. Grounded electrodes
26 422 and 424 may be disposed within the chambers 414 and 420

1 respectively, and the chamber walls of chambers 414 and 420 may
2 likewise be grounded. It is therefore to be appreciated that the electrical
3 circuit 400 permits two reactor chambers to be driven by a single RF
4 generator 404 with a single matching network 406 in a electrical circuit
5 that automatically adjusts for differing impedance loading within each
6 chamber 414 and 420, such that uniform plasmas are created in both
7 chambers. It is to be appreciated that the electrical circuit 400 of Fig. 6
8 and the electrical circuit concepts of Fig. 5 may be combined in various
9 ways to provide RF power to a plurality of reactor chambers having at
10 least one but perhaps several powered electrodes disposed within the
11 various reactor chambers. The utilization of self-tuning circuit
12 components, such as the differential drive transformers and/or center-
13 tapped coils results in a self-tuning electrical circuit that provides for
14 uniform plasmas among similarly powered electrodes.

15
16 Generally, the power-splitting concept of the present invention for
17 creating plasmas in relation to a plurality of powered electrodes may be
18 constructed where the number of powered electrodes is a number (N)
19 which is equal to an integer greater than 1. The reactive circuit elements,
20 such as 302, 304, 306, 308 and 310 of Fig. 5 may be either center-tapped
21 coils or differential drive transformers, and the number of reactive
22 circuit elements will be equal to the number (N) of powered electrodes
23 minus one. Thus, a circuit of the type depicted in Fig. 5 may have a number
24 (Y) of reactive circuit elements including a number (D) of differential
25 drive transformers, a number (C) of center-tapped coils; where $Y = C + D$,
26 and where $Y = N - 1$ and further where N is an integer greater than 1.

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1
2 While the invention has been particularly shown and described
3 with reference to certain preferred embodiments, it will be understood by
4 those skilled in the art that various alterations and modifications in form
5 and detail may be made therein. Accordingly it is intended that the
6 following claims cover all such alterations and modifications as may fall
7 within the true spirit and scope of the invention.

8
9 What I claim is:

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IN THE CLAIMS

1. A multiple electrode plasma reactor power circuit comprising:
an RF generator;
a matching network being electrically connected to said RF generator;
at least one reaction chamber having a total of at least two powered electrodes disposed within said chambers and at least one grounded surface disposed in each said chamber, said powered electrodes and said grounded surfaces being positioned relative to each other such that at least one plasma for each powered electrode is created upon the application of RF power thereto;
an electrode power circuit disposed between said matching network and said powered electrodes to feed RF power from said matching network to said powered electrodes; said electrode power circuit including a circuit means having an input power line connected from said matching network and having output power lines connected to said powered electrodes and operative to split said RF power among said powered electrodes, said circuit means being automatically reactive to changes in the impedance between various ones of said powered electrodes and said grounded surfaces to alter the RF power applied to each said powered electrode to balance said plasmas generated between each said powered electrode and said ground surfaces.

1 2. A multiple electrode plasma reactor as described in Claim 1
2 wherein said circuit means includes at least one differential drive
3 transformer.
4

5 3. A multiple electrode plasma reactor power circuit as described in
6 Claim 2 wherein each said powered electrode is electrically connected to
7 an output line from a differential drive transformer.
8

9 4. A multiple electrode plasma reactor power circuit as described in
10 Claim 1 wherein two powered electrodes are disposed within one said
11 chamber and one grounded electrode is disposed within said chamber
12 between said two powered electrodes; and

13 said circuit means includes a differential drive transformer
14 having two output lines wherein each said powered electrode is connected
15 to one of said two output lines.
16

17 5. A multiple electrode plasma reactor power circuit as described in
18 Claim 4 wherein said differential drive transformer includes an output
19 coil having two output ends, each said output end being electrically
20 connected to one of said powered electrodes; said output coil being
21 electrically connected to ground at a center tap thereof and wherein a DC
22 blocking capacitor is electrically connected in said electrical circuit
23 between each said powered electrode and said grounded center tap of said
24 differential drive transformer.
25

1 6. A multiple electrode plasma reactor power circuit as described in
2 Claim 1 wherein said circuit means includes at least one center-tapped
3 coil, each said center-tapped coil having two output ends, and wherein
4 each said powered electrode is connected to an output end of a center-
5 tapped coil; and wherein said matching network is connected to the center
6 tap of a center-tapped coil.

7

8 7. A multiple electrode plasma reactor power circuit as described in
9 Claim 1 wherein two powered electrodes are disposed within one said
10 chamber and one grounded electrode is disposed within said chamber
11 between said two powered electrodes; and

12 said circuit means includes a center-tapped coil having said input
13 power line connected to the center tap of said coil, and said coil having
14 two output lines wherein each said powered electrode is connected to one
15 of said two output lines.

16

17 8. A multiple electrode plasma reactor power circuit as described in
18 Claim 1 wherein said circuit means includes a number (Y) of circuit
19 elements including a number (D) of differential drive transformers and a
20 number (C) of center-tapped coils, and wherein $Y = D + C$ and wherein said
21 chamber includes a number (N) of powered electrodes, wherein $Y = N - 1$,
22 and wherein N is an integer greater than 1.

23

24 9. A multiple electrode plasma reactor comprising:
25 a chamber being defined by walls within which plasmas are
26 created;

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1 a plurality of powered electrodes and at least one grounded
2 surface being disposed within said chamber whereby said plasmas are
3 struck between said powered electrodes and said grounded surface;

4 said powered electrodes being connected to an RF power splitting
5 circuit means, said circuit means being joined at an RF power input
6 thereof to an RF power source;

7 said circuit means being reactive to differing impedances between
8 said powered electrodes and said grounded surface to alter the RF power
9 supplied to each said powered electrode to balance the plasmas generated
10 between each said powered electrode and said grounded surface.

11
12 10. A multiple electrode plasma reactor as described in Claim 9
13 wherein a grounded electrode is disposed between each said powered
14 electrode.

15
16 11. A multiple electrode plasma reactor as described in Claim 10
17 wherein said powered electrodes and said grounded electrodes are formed
18 as planar members and disposed within said chamber such that an equal
19 distance exists between each said powered electrode and grounded
20 electrode.

21
22 12. A multiple electrode plasma reactor as described in Claim 11
23 wherein said circuit means includes a number (Y) of circuit elements
24 including a number (D) of differential drive transformers and a number (C)
25 of center-tapped coils, and wherein $Y = D + C$ and wherein said chamber

- 1 includes a number (N) of powered electrodes, wherein $Y = N - 1$, and
- 2 wherein N is an integer greater than 1.

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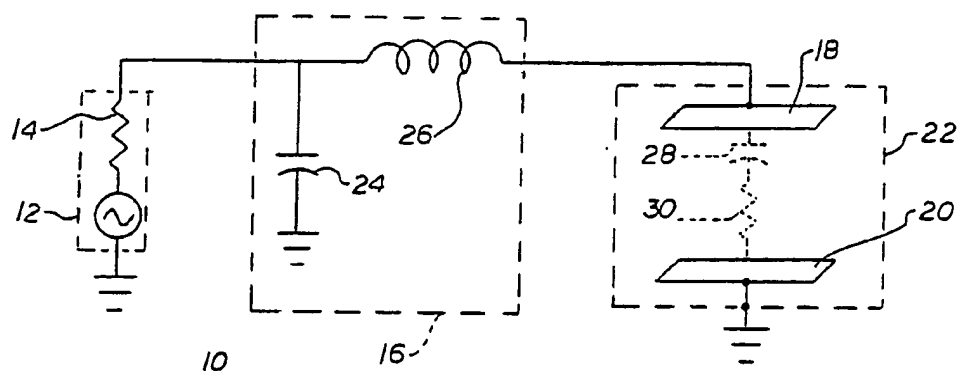


FIG. 1

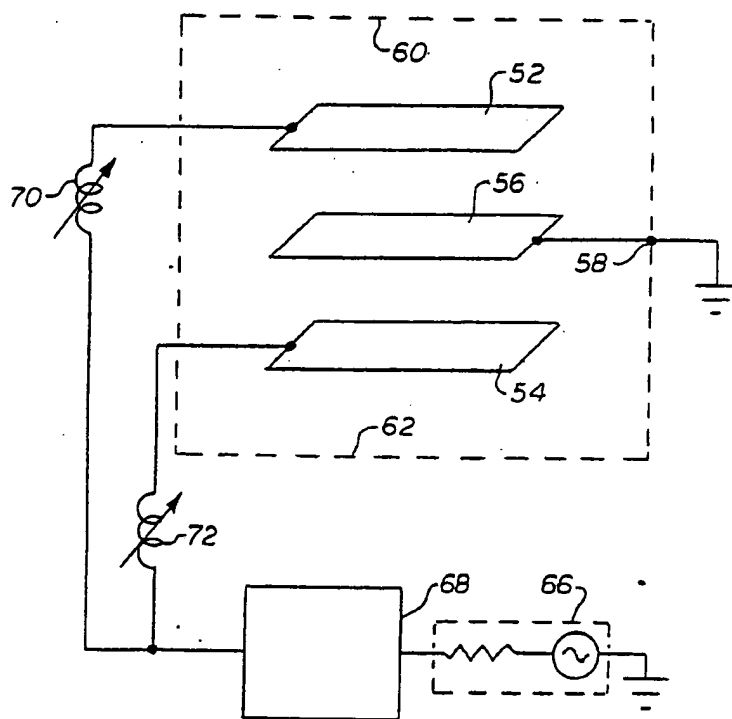


FIG. 2

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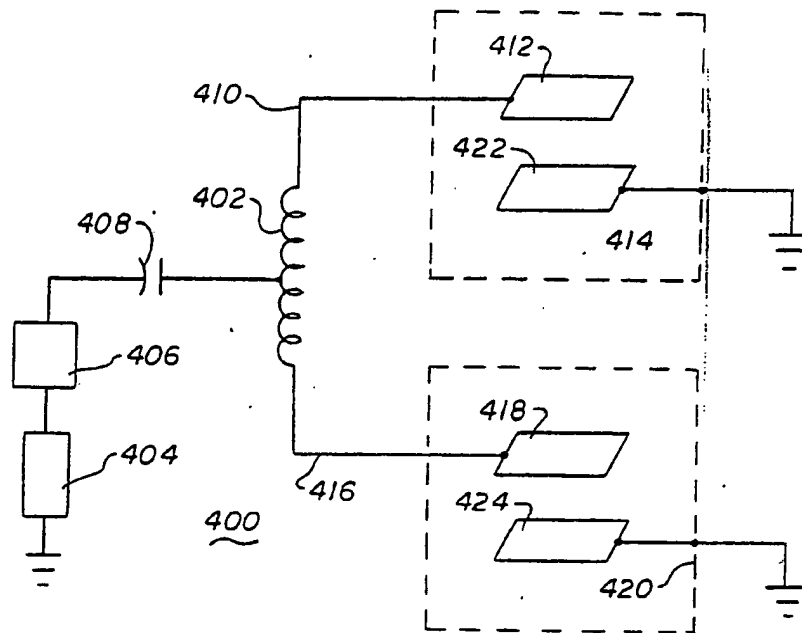


FIG. 6

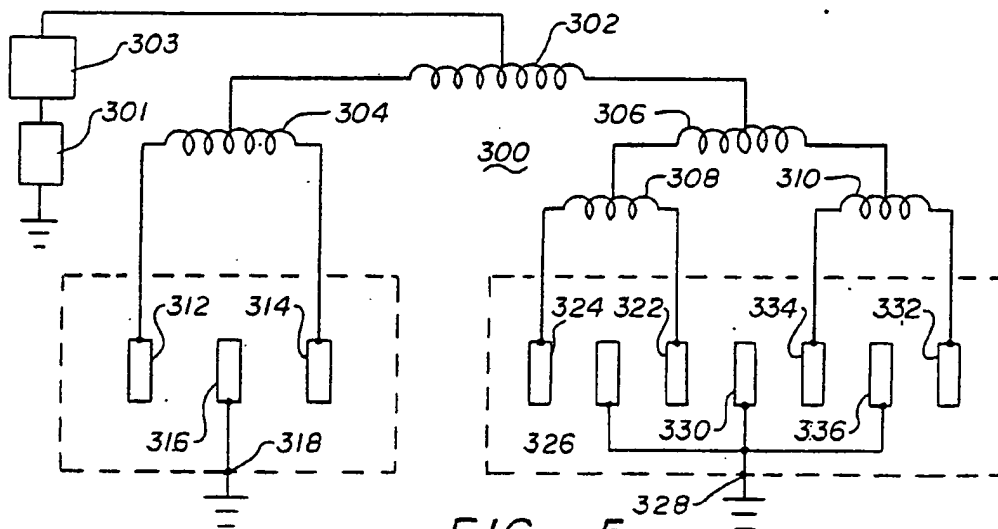
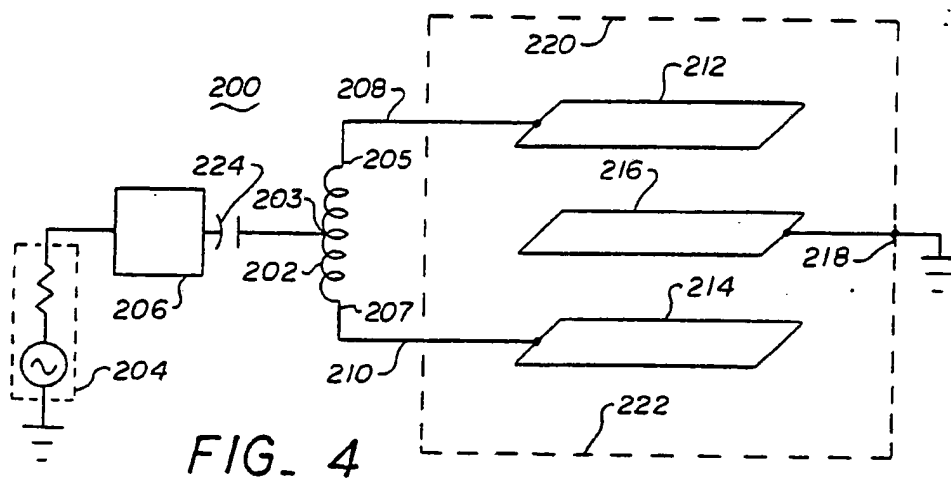
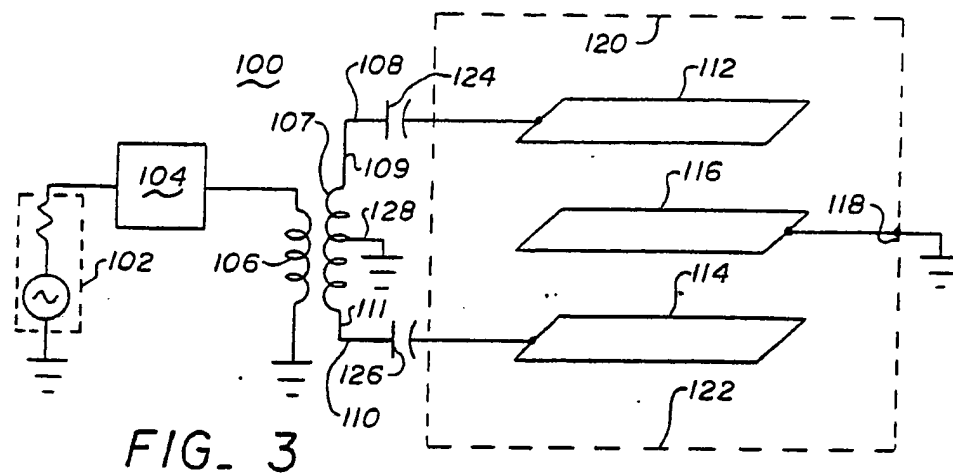


FIG. 5


SUBSTITUTE SHEET

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INTERNATIONAL SEARCH REPORT

International Application No. PCT/US88/03184

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ⁶		
According to International Patent Classification (IPC) or to both National Classification and IPC IPC(4): H05B 31/28 U.S. CL: 315/111.21, 111.81, 111.91, 111.51, 111.71; 204/192.32, 121, 146; 219/121.54, 121.57, 10.55 F		
II. FIELDS SEARCHED		
Minimum Documentation Searched ⁷		
Classification System	Classification Symbols	
US	315/111.21, 111.81, 111.91, 111.51, 111.71; 204/192.32, 121, 146; 219/121.54, 121.57, 10.55 F	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched ⁸		
III. DOCUMENTS CONSIDERED TO BE RELEVANT ⁹		
Category ⁹	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
Y	US, A, 4,381,965 (Maher, Jr. et al) 3 May 1983 See Figs. 4-5, 9, and Col. 7, lines 44-66.	1-12
Y	US, A, 4,724,296 (Morley) 9 February 1988 See Fig. 1, and Col. 2, lines 64-68 and Col. 3 lines 1-30.	
A	US, A, 4,282,077 (Reavill) 4 August 1981 See Fig. 2 and text.	1-12
A	US, A, 4,446,560 (Gabor) 1 May 1984 See Figs. 1, 3-4 and text.	
<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p>¹⁰ Special categories of cited documents:</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the International filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the International filing date but later than the priority date claimed</p> </div> <div style="width: 45%;"> <p>"T" later document published after the International filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"&" document member of the same patent family</p> </div> </div>		
IV. CERTIFICATION		
Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report	
8 December 1988	16 FEB 1989	
International Searching Authority	Signature of Authorized Officer	
ISA/US	 Michael Razavi	